PREPARATION AND EVALUATION OF COMPOSITE MATERIAL MADE USING HIGH LIME WASTE BY-PRODUCT AND PREPARATION PLANT COARSE REFUSE (Part of the Program of the Federal Panel on Energy R&D (PERD)

FINAL REPORT BY

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EXECUTIVE SUMMARY

Acid drainage associated with the oxidation of pyritic slates in several areas of Nova Scotia, have contributed to the degradation of surface and groundwater supplies. The waste generated at the Victoria Junction coal preparation plant contains pyrite with a potential through oxidation to cause acid runoff.

Cementitious materials have been used to stabilize waste so as to limit the quantity of leachates available for release into the groundwater regime. The purpose of this research project was to study the feasibility of using a circulating fluidized bed combustion (CFBC) ash to stabilize the coal preparation plant waste. The CFBC ashes contain a high percentage of calcium by virtue of the CFBC process. The calcium is generally in the oxide (CaO) form or sulphate ($CaSO_4$) form. The sulphur is derived from the coal. Sixteen concrete mixtures were studied using various combinations of CFBC ash, Lingan Class F fly ash, Portland cement and preparation plant waste.

Strength testing on prepared specimens from the above concrete mixtures, showed a strength regression with time after the initial hydration process. This strength regression was considered due to the change which occurs in the form of calcium sulphate from $CaSO_4$ to $CaSO_4 \cdot 2H_2O$. There is an accompanying expansion which reduces the integrity of the bonding in the system. Also, the mixture could not be adequately air entrained for long term freezing and thawing durability, thus, the original program was terminated at this stage.

An alternative method to stabilization of waste, is that of encapsulation to reduce the rate of water infiltration. A second phase of the program studied the performance of four proposed cementitious sealants for the purpose of encapsulation. These concrete mixtures consisted of Portland cement, Lingan Class F fly ash, silica fume, concrete sand and small sized gravel. The mixtures were designed to be placed by the shotcrete process. The mixtures also incorporated polypropylene fibres at a dosage of 4 kg/m^3 to reduce the potential for plastic cracking to occur, and also to provide ductility to the concrete sealant. Each of the four sealants exhibited excellent freeze-thaw durability and mechanical properties.

A third phase of the program included the shotcreting of a test panel of a selected concrete mixture, at the Halifax International Airport. This particular site was selected for the trial panel since a prepared base was available from a previous research project. The site is equipped with a collection system to monitor water infiltration. The mechanical properties of the concrete have been studied for laboratory cured, field cured, and cored specimens. The performance to date has been excellent. Future monitoring will include visual examination and infiltration measurement.

Keywords: Sealants, fly ash, shotcrete, polypropylene fibres, mechanical properties, silica fume, freeze-thaw durability.

INTRODUCTION

Jacques, Whitford and Associates Limited entered into a contract entitled "Preparation and Evaluation of Composite Material Made Using High Lime Waste By-Product and Preparation Plant Coarse Refuse" with the Cape Breton Development Corporation. The above contract was signed on December 31, 1988.

Work on the stabilization indicated that a durable, stable mixture could not be obtained due to an expansion (change in the form of $CaSO_4$) which lead to a gradual degradation of the cementitious component. Based on success of a high fly ash content shotcrete sealant study at the Halifax International Airport, it was recommended that the scope of the original contract be changed to investigate the use of this technology for stabilization of waste stockpiles. The contract was amended to encompass this work and a work statement issued and authorization to proceed was issued on January 2, 1991.

Work on the revised statement of work commenced on February 5, 1991 and a report was issued in October, 1991. Four cementitious materials were evaluated for sealants. Each of the sealants performed well in laboratory tests. The most economical sealant was utilized in a test panel at the Halifax International Airport on November 7, 1991. Authorization for this work was via facsimile on October 10, 1991.

For the convenience of the reader, this final report is presented in three phases; each phase reporting on the particular work performed for each revised statement of work. The three phases are as follows:

Phase I	Preparation and Evaluation of Composite Material Made Using CFBC High Lime Waste By-Product and Preparation Plant Coarse Refuse
Phase II	Laboratory Evaluation of Four Cementitious Sealants for Waste Stabilization
Phase III	Test Panel at the Halifax International Airport

Each of the above Phase reports are intended to be self-contained.

In summary, the Phase I report found that due to the expansion associated with gypsum in the CFBC waste, the preparation plant coarse refuse could not be stabilized for long term durability.

Phase II investigated four cementitious sealants incorporating Portland cement, fly ash and silica fume. Each of these mixtures possessed adequate strength and durability requirements for durable encapsulation materials.

Phase III indicated that the mixtures developed in Phase II could be placed by the shotcrete method, and to date a test panel has performed adequately. The test panel will be monitored and infiltration rates measured after the panel develops shrinkage cracks.

PREPARATION AND EVALUATION OF COMPOSITE MATERIAL MADE USING HIGH LIME WASTE BY-PRODUCT AND PREPARATION PLANT COARSE REFUSE PHASE I

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1.0 INTRODUCTION

A study was conducted on the feasibility of utilizing a circulating fluidized bed combustion (CFBC) ash for the stabilization of the preparation plant coarse refuse from the Devco Victoria Junction plant. The CFBC ash was obtained from a trial run at CFB Chatham using Lingan coal. Only the fly ash was utilized in trial concrete mixtures, i.e., the bottom ash was not utilized. In addition to using the CFBC ash above, various combinations of normal Portland cement, Lingan Class F fly ash and CFBC ash were tested in concrete mixtures. Acceptability of the CFBC ash for use in concrete mixtures was to be based on the mechanical properties of air-entrained concrete. It should be noted that the characteristics of the CFBC ash is not only dependent on the source of coal, but also on the characteristics of the limestone used.

1.1 Materials

The Chatham ash was characterized by CANMET/MSL in Mineral Sciences Laboratories Division Report MSL 89-2 (CR). The average chemical and physical test values for nine samples of the CFBC ash are shown in Table 1.1.

The Lingan fly ash used in the study was a Class F fly ash collected from the thermal generating plant in Lingan, Nova Scotia. Properties of the Lingan ash are documented in Table 1.2.

Portland cement normal Type 10 manufactured by Canada Cement Lafarge in Brookfield, Nova Scotia was used in all mixtures containing Portland cement. The physical and chemical properties of the Portland cement are shown in Table 1.2.

The preparation plant coarse refuse was used in concrete mixtures as sampled from the stockpile. A neutralized Vinsol resin was used as an air-entraining agent.

1.2 Concrete Mixtures

All concrete mixtures were mixed in an Eirich Counter current mixer of 0.15 m^3 capacity. The composition of the mixtures and properties measured on the fresh concrete are shown in Table 1.3.

Preconditioning studies performed by CANMET noted that CaO in the ash quickly changed to the hydrated form $Ca(OH)_2$ and that $CaSO_4$ changed to $CaSO_4$ $1/2H_2O$. During these reactions, considerable heat was generated and it was found that the temperature stabilized at 18% added water. Prehydration reduced the strength of mortars relative to the use of non-prehydrated ash.

Concrete mixtures were performed only with the non-prehydrated ash; thus, the water demand was relatively high to reflect the initial hydration of ash components and the temperature of the mixtures increased some 10 to 15°C above ambient temperature. The water content in normal concrete mixtures would be in the range of 160 l per cubic metre.

The concrete mixtures could not be adequately air-entrained even with inordinately high dosages of air-entraining agents. This is believed due to the high carbon content of the ash and plant waste material.

1.3 Mechanical Properties of Concrete Mixtures

Tables 1.4, 1.5 and 1.6 tabulate the mechanical properties of compressive strength, splitting tensile strength and flexural strength, respectively.

Compressive strength tests were performed at ages of 7, 28 and 91 days. All of the strength values at 7 days were relatively low, with those containing the highest Portland cement content and low Chatham ash content showing the highest strength values. Strength gain from 7 to 28 days was generally low with a subsequent strength loss from 28 to 91 days. The strength regression is believed due to the expansion which occurs in the cementitious system as the $CaSO_4$ $1/2H_2O$ changes to $CaSO_4$ $2H_2O$. Several specimens self-destructed such that test values could not be obtained.

The splitting tensile strength generally followed the trend of the compressive strength with low to moderate strength gain from 7 to 28 days. The ratio of splitting tensile strength to compressive strength was in the same order of magnitude as for normal concrete (approximately 0.12).

The flexural strength measured on prisms from each of the mixtures was very low. Most of the specimens were too fragile for testing and only mixtures 1 to 5, inclusive, and mixtures 12 to 16 inclusive, could be tested. The cross sectional area of the prisms is less than for the compressive strength and splitting tensile test specimens, thus, the flexural specimens are more sensitive to the deleterious effects of expansions.

1.4 Analyses of Test Results

The uncontrolled expansion during the formation of the calcium sulphate hemi-hydrate ($CaSO_4$ $1/2H_2O$) and the calcium sulphate dihydrate ($CaSO_2$ $2H_2O$) causes the concrete to regress in strength and durability, when the Chatham ash is used in concrete mixtures. Moderate percentages of normal Portland cement added to the cementitious material is not sufficient to ameliorate the expansions.

Studies of the Chatham ash disposal sites have also shown that the material has a strength regression with time. Samples of the ash in a particular asphalt cell showed a strength of 1840 kPa at 7 days, 2490 kPa at 157 days and only 117 kPa at 533 days. These tests were for the ash only and cured at ambient temperatures under natural outdoor conditions.

Due to the degradation of strength with increasing age and in the inability to entrain air in the system, necessary for long term durability, it is unlikely that the system studied would have any significant engineering application within the parameters studied. It is obvious that further refinement would be required to develop a system to withstand a harsh environment.

TABLE 1.1

PHYSICAL AND CHEMICAL PROPERTIES OF CFBC ASH

CFBC Ash Characterization	
Relative Density	2.86
Fineness (Blaine)	3408 cm 2/g
Carbon (Total)	7.71%
Carbon (Mineral)	0.65%
Sulphur	6.34%
Chemical Properties	
SiO_2	13.01%
Al_2O_3	6.71%
Fe_2O_3	15.11%
TiO_2	0.27%
P_2O_5	0.05%
CaO	34.53%
MgO	1.46%
SO_3	17.57%
Na_2O	0.29%
K_2O	0.79%
Forms of Ca (% by Weight)	
$CaSO_4$	29.87
$CaCO_3$	5.41
CaO	19.21

TABLE 1.2 - PHYSICAL PROPERTIES AND CHEMICAL ANALYSIS OF PORTLAND CEMENT AND FLY ASH

	Normal Portland Cement ASTM Type 1	Fly Ash Low Calcium (ASTM Class F)
PHYSICAL PROPERTIES		
FINENESS		
Passing 45 um sieve	93.1%	84%
Surface area, Blaine	398 m2/kg	351 m2/kg
VICAT SETTING TIME		
Initial	155 min.	
Final	315 min.	
COMPRESSIVE STRENGTH		
3 day	23.8 MPa	
7 day	30.1 MPA	
28 day	36.7 MPA	
POZZOLANIC ACTIVITY INDEX		
Water requirement		88%
Activity Index, 28 day		97%
CHEMICAL ANALYSIS		
Silicon dioxide (SiO2)	21.06%	45.2%
Aluminum oxide (Al2O3)	4.59%	20.7%
Ferric oxide (Fe2O3)	2.30%	24.8%
Calcium oxide (CaO)	62.28%	1.63%
Magnesium oxide (MgO)	2.81%	0.97%
Suphur trioxide (SO3)	2.53%	0.65%
Sodium oxide (Na2O)	0.50%	0.59%
Potassium oxide (K2O)	0.49%	2.40%
Loss on ignition	2.61%	2.66%
Insoluble residue	1.01%	-
BOGUE POTENTIAL COMPOUND COMPOSITION		
C3S	52%	
C2S	21%	
C3A	8.3%	
C4AF	7.0%	

Table 1.3 Mixture Composition and Mixing Data

Mixture Composition, kg/m3						Properties of Plastic Mixture			
Mixture No.	CFBC Ash	Lingan Fly Ash	Coarse Refuse	Portland Cement	Water	Slump mm	Air Content %	Mass Density kg/m3	Mixture Temp, C
1	183	–	1644	–	233	0	1.7	2060	32
2	377	–	1433	–	287	90	2.0	2078	34
3	525	–	1224	–	298	90	1.5	2046	39
4	664	–	996	–	346	100	3.0	2097	43
5	185	185	1479	–	254	75	1.3	2103	35
6	183	367	1283	–	273	85	1.5	2106	34
7	350	175	1226	–	176	75	1.5	2046	32
8	342	342	1027	–	320	90	2.0	2032	35
9	494	165	987	–	346	90	2.1	1993	33
10	620	310	620	–	388	100	4.0	1939	37
11	671	335	671	–	337	90	2.9	2014	34
12	353	–	1324	88	300	85	1.2	2064	29
13	364	–	1272	182	288	80	1.3	2106	33
14	358	–	1075	358	314	85	1.5	2106	32
15	520	–	1040	174	311	120	1.9	2046	34
16	178	–	1427	178	289	75	1.8	2071	33

Table 1.4 Compressive Strength of Cylinders

Composition, % by Mass					Compressive Strength, MPa		
Mixture No.	Chatham Ash	Lingan Fly Ash	Coarse Refuse	Portland Cement	Age of Specimens (days)		
					7	28	91
1	10	–	90	–	0.4	0.4	Self Destructed
2	20	–	80	–	0.7	2.3	Self Destructed
3	30	–	70	–	1.4	3.7	2.2
4	40	–	60	–	1.3	1.7	2.4
5**	10	10	80	–	1.4*	2.7	2.4
6**	10	20	70	–	2.7*	3.5	3.3
7	20	10	70	–	2.1*	6.3	1.6
8	20	20	60	–	2.9*	7.9	7.9
9	30	10	60	–	3.3*	6.1	–
10	40	20	40	–	3.0	4.9	2.9
11	20	40	40	–	1.8	3.0	6.6
12	20	–	75	5	2.7	1.3	1.3
13	20	–	70	10	5.3	6.6	5.3
14	20	–	60	20	8.9	10.7	9.3
15	30	–	60	10	4.9	7.1	5.4
16	10	–	80	10	3.2	3.2	2.0

* Test age 10 days.
** Not moist cured.

Table 1.5 Splitting Tensile Strength of Cylinders

Composition, % by Mass					Splitting Tensile Strength, kPa	
Mixture No.	Chatham Ash	Lingan Fly Ash	Coarse Refuse	Portland Cement	Age of Specimens (days) 7	28
1	10	–	90	–	71	79
2	20	–	80	–	41	300
3	30	–	70	–	168	443
4	40	–	60	–	141	271
5**	10	10	80	–	198*	316
6**	10	20	70	–	288*	421
7	20	10	70	–	234*	685
8	20	20	60	–	303*	1069
9	30	10	60	–	412*	428
10	40	20	40	–	366	525
11	20	40	40	–	232	359
12	20	–	75	5	236	146
13	20	–	70	10	651	714
14	20	–	60	20	857	1150
15	30	–	60	10	540	679
16	10	–	80	10	370	373

* Test age 10 days.
** Not moist cured.

Table 1.6 Flexural Strength of Beams

Composition, % by Mass					Modulus of Rupture, MPa	
Mixture No.	Chatham Ash	Lingan Fly Ash	Coarse Refuse	Portland Cement	Age of Specimens (days) 7	28
1	10	–	90	–	0.55	–
2	20	–	80	–	0.34	0.42
3	30	–	70	–	0.91*	0.83
4	40	–	60	–	0.42	1.10
5	10	10	80	–	0.29*	
6	10	20	70	–		0.88*
7	20	10	70	–		
8	20	20	60	–		
9	30	10	60	–		
10	40	20	40	–		
11	20	40	40	–		
12	20	–	75	5	0.66	
13	20	–	70	10	1.45	1.78
14	20	–	60	20	1.90	1.90
15	30	–	60	10	1.52	1.90
16	10	–	80	10	1.17	1.27

* Demoulded at 7 days.

LABORATORY EVALUATION OF FOUR CEMENTITIOUS SEALANTS FOR WASTE STABILIZATION

PHASE II

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2.0 INTRODUCTION

The following paragraphs outline in detail the work performed in accordance with our work statement of February 5, 1991. A copy of the work statement is included in Appendix A. The objective of the work was to develop an economical cementitious sealant to be utilized in stabilizing waste material. The cementitious mixtures were designed to provide an optimum mixture for economy, placement and durability.

2.1 Laboratory Studies

Laboratory mixtures were performed in the Dartmouth Laboratories of Jacques, Whitford and Associates Limited for four cementitious combinations. The following materials were utilized.

2.1.1 Portland Cement

Normal Portland cement, CSA Type 10 was used in mixtures 1, 2 and 3. A silica fume blended cement was used in Mixture 4. The physical and chemical properties of the cements are shown in Tables 1 and 2.

2.1.2 Fly Ash

The fly ash used in the study was a low-calcium fly ash (ASTM Class F) from the coal fired thermal generating plant in Lingan, Nova Scotia. The characteristics of the fly ash are shown in Table 1 and 2.

2.1.3 Aggregate

A natural sand and gravel, processed for the concrete industry was used as aggregate. The combined grading met the requirements of ACI 506.2 - Grading No. 2. The gradation and physical properties of the aggregate are shown in Table 3.

2.1.4 Superplasticizer

The superplasticizer (high range water reducing admixture) was an aqueous solution of naphthalene sulphonate formaldehyde condensate. The solution contained 40 percent solids by mass.

2.1.5 Air-Entraining Admixtures

A neutralized vinsol resin was used as an air-entraining admixture.

2.1.6 Fibres

A polypropylene fibrillated fibre of 19 mm nominal length was used in all mixtures.

2.2 Mixture Proportions

The proportioning of the concrete mixtures are summarized in Table 4. The aggregate was stored in the laboratory for 24 hours and the free moisture determined, and added as the appropriate proportion of mixture water. The mixtures were proportioned for cementitious contents, varying form 375 to 400 kg per cubic metre and fibre content of 4 kg per cubic metre.

The concrete mixtures were made in a laboratory counter current mixer with the fly ash and silica fume added as a separate component, with the exception of the silica fume blended cement. The fibres were added with part of the superplasticizer and the slump adjusted after all the fibres were intermixed. The fibres do not disperse well in a high slump mixture.

2.3 Properties of Fresh Concrete

The properties of the fresh concrete, i.e. temperature, slump, air content and mass density are shown in Table 5.

2.4 Preparation and Casting of Test Specimen

Cylindrical specimens 150 x 300 mm were cast and standard moist cured for compressive strength testing at 3, 7, 28 and 91 days. Three specimens were cast for each test date and for each concrete mixture. Young's Modulus of elasticity was also determined on 150 x 300 mm cylinders. Each reported value is the average of two test specimens.

Flexural tests were performed on prisms measuring 75 mm x 100 mm x 405 mm. Each test value at 28 and 91 days is the average of three test specimens.

After casting, all the moulded specimens were covered with non absorptive coverings and left in the casting room at 23 $\pm$ 1.7°C and 50 percent relative humidity for 24 hours, at which time the specimens were de-moulded and transferred to the standard curing conditions at 100 percent relative humidity.

2.5 Testing of Specimens

The testing schedule for the mechanical properties of the hardened concrete is shown in Table 6. All specimens were tested in accordance with applicable CSA standards where available, otherwise ASTM test standards were used.

The results of testing of the four laboratory concrete mixtures are summarized in Table 6.

2.6 Freeze-Thaw Tests

The results of freeze-thaw tests are included in Appendix B. All four mixtures showed a relative dynamic modulus of elasticity in excess of 100 percent at 300 cycles. This is indicative of good freeze-thaw durability.

2.7 Conclusions

Based on the laboratory studies of the four concrete mixtures, mixture number 4 is considered the most suitable for shotcrete application to stabilize stockpiles. All of the mixtures show excellent durability, however, mixture number 4 has a good combination of strength and economy.

TABLE 1 – CHEMICAL ANALYSIS OF CEMENTITIOUS MATERIAL

Component	Type 10	Type HSF	Fly Ash
SiO2	20.60%	28.00%	45.20%
Al2O3	4.30%	4.00%	20.70%
Fe2O3	1.80%	1.60%	24.80%
CaO	62.60%	58.00%	1.63%
MgO	2.80%	2.80%	0.97%
SO3	2.80%	2.80%	0.65%
Na2O (Equiv.)	0.73%	0.75	2.19%

TABLE 2 – PHYSICAL PROPERTIES OF CEMENTITIOUS MATERIAL

Properties	Type 10	Type HSF	Fly Ash
Initial Set	160 min	160 min	–
Final Set	300 min	–	–
Percent Finer Than 45 µm	90.4	94.0	84%
Blaine Fineness	380 m2/kg	560 m2/kg	351 m2/kg
SOUNDNESS			
– Autoclave Expansion	0.12%	0.08%	–
COMPRESSIVE STRENGTH 2 INCH CUBES			
– 24 hr	–	14.0 MPa	–
– 3 d	22.0 MPa	26.0 MPa	–
– 7 d	28.0 MPa	34.0 MPa	–
– 28 d	35.0 MPa	48.0 MPa	–
POZZOLANIC ACTIVITY			
– Water Requirement	–	–	88%
– Activity Index, 28 days	–		97%

TABLE 3 – PROPERTIES OF AGGREGATE

Gradation Analysis	
Sieve Size (mm)	Percent Finer
10	100
5	74
2.5	63
1.25	48
0.630	30
0.315	12
0.160	3.5
Relative Density	2.61
Absorption	1.30
Soundness (Na_2SO_4), Average Loss (%	6.33

TABLE 4 – MIXTURE PROPORTIONS

	Mixture Number			
	1	2	3	4
Portland Cement kg/m3	102	126	92	–
HSF Cement kg/m3	–	–	–	126
Fly Ash kg/m3	280	252	288	252
Silica Fume kg/m3	25	10	10	–
10 mm Aggregate kg/m3	525	515	525	520
Sand kg/m3	1200	1205	1225	1210
Polypropylene Fibres kg/m3	4	4	4	4
Water L/m3	142	141	144	141
Air Entraining Admixture mL/m3	249	195	199	194
Superplasticizer L/m3	5.4	5.0	5.2	5.6
Water Reducer L/m3	1.02	0.98	0.98	0.94

TABLE 5 – PROPERTIES OF FRESH CONCRETE

	Mixture Number			
	1	2	3	4
Concrete Temperature oC	23	25	25	25
Initial Slump, mm	50	130	150	115
Final Slump, mm	140	160	200	160
Initial Air Content %	6.2	7.2	8.5	7.6
Final Air Content %	6.5	7.2	6.6	7.2
Mass Density kg/m3	2266	2251	2287	2244

TABLE 6 – MECHANICAL PROPERTIES OF HARDENED CONCRETE

	Mixture Number			
	1	2	3	4
Compressive Strength, MPa				
3 day	6.1	8.6	6.0	7.9
7 day	12.5	13.8	9.5	11.8
28 day	27.7	27.6	22.2	25.0
91 day	36.1	39.0	29.1	38.4
Flexural Strength, MPa				
28 day	4.40	4.31	3.29	3.80
91 day	5.08	5.65	5.09	6.14
Modulus of Elasticity, GPa				
28 day	23.4	21.6	20.1	22.0
91 day	23.2	24.4	24.6	21.3

TEST PANEL AT THE HALIFAX INTERNATIONAL AIRPORT

PHASE III

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3.0 INTRODUCTION

W. S. Langley and Associates Limited carried out a field evaluation of pyritic slate sealers at the Halifax International Airport. One test areas consisted of a gravel covered polyethylene membrane. The program at the airport concluded in December 1990 and through negotiations with the Transport Development Centre, the polyethylene barrier site was made available for use to further evaluate the sealants studied in the laboratory for the Cape Breton Development Corporation.

The principal purpose of the field testing program was to physically measure the amount of infiltration through the cementitious sealant. The polyethylene barrier provided an excellent opportunity to collect and channel any water to a central collecting point.

3.1 Site and Site Preparation

A high density polyethylene liner was installed on a sloped area near the airport maintenance facility. The liner was 60 mil (1.5 mm) in thickness and 15 m x 30 m in area. The area was levelled and the vegetation removed prior to placing the liner. The liner was covered with approximately 200 mm of gravel to reduce the risk of surface damage and deterioration. A filter fabric was installed at the toe of the slope to prevent fines from the gravel escaping into the myriad of small brooks adjacent to the site. The edges of the polyethylene were rolled up to prevent the escape of water to the sides. A four inch (100 mm) diameter plastic pipe was cemented through the toe filter and polyethylene membrane at the low port of the barrier, so as to collect all infiltrating water at a central point.

3.2 Sealant Composition

Mixture No. 4, established in Phase II of the study program was selected for the field study. This particular mixture was selected based on laboratory performance and low cost. The composition of the mixture is repeated below:

Silica Fume Blended Cement	126 kg/m^3
Lingan Fly Ash	252 kg/m^3
10 mm Aggregate	520 kg/m^3
Concrete Sand	1210 kg/m^3
Polypropylene Fibres	4 kg/m^3
Water	141 L/m^3
Air Entraining Agent	194 ml/m^3
Water Reducer	0.94 L/m^3
Superplasticizer	5.6 L/m^3

Slight variations occurred in mixture proportions at the batch plant and the superplasticizer dosage ranged from 4.4 L/m^3 to 7 L/m^3.

The concrete arrived at the site in 5 to 6 m^3 truck loads for a total of 28.5 m^3. The superplasticizer and fibres were added to each truck on site.

3.3 Sealant Placement

The sealant concrete was placed some 50 mm thick by the shotcrete process. By this process, the concrete of proper consistency is discharged into a piston pump which forces the concrete through a pump line to a 50 mm nozzle at which point compressed air blows the concrete in place. The air pressure is sufficient to compact the concrete into a dense mass without further vibration.

The concrete is air entrained at the batch plant so as to be durable in the presence of freeze-thaw cycles. Part of the air entrainment is lost during the shotcrete process, thus the initial air content must be sufficient to allow for losses during placement. Table 3.1 summarizes the data on slumps and air content for each truck load of concrete.

3.4 Casting and Curing of Test Specimens

Specimens were cast in the field for site cured testing and laboratory testing.

3.4.1 Site Cured Specimens

Test cylinders (150 mm x 300 mm) were cast for compression testing at 7, 28, 91 and 365 days, and were left to cure with the panel. These cylinders were cured with the test panel at ambient conditions. The cylinders were left at the site until 48 hours prior to testing, at which time they were taken to the laboratory and immersed and moist cured in water.

Specimens were also fabricated for splitting tensile testing and modulus of elasticity.

3.4.2 Laboratory Cured Specimens

Compressive strength specimens (150 mm x 300 mm) were cast at the site and transported to the laboratory after 24 hour site curing for testing at 7, 28, 91 and 365 days. Three specimens were cast for each test age. Three cylinder specimens 150 mm x 300 mm in size, were cast for splitting-tensile testing at each of 28, 91 and 365 days. Specimens were also cast for the determination of the modulus of elasticity at 28, 91 and 365 days.

3.4.3 Drilled Cores

The 150 mm x 300 mm cores were drilled vertically through a thickened section of the panel. The cores were used to determine the compressive strength, modulus of elasticity, mass density and pulse velocity. The cores were soaked in water for 48 hours at 23 $\pm$ 2°C prior to testing. All testing was performed in accordance with standard CSA or ASTM test procedures.

The mechanical properties of the hardened concrete for each test condition are summarized in Table 3.2.

3.5 Conclusion

A test panel some 15 m x 30 m in extent and 50 mm thick has been installed and monitored at the Halifax International Airport. The panel was constructed with concrete containing a high volume of low calcium fly ash (to reduce initial cost and drying shrinkage) and a relatively high volume of polypropylene fibres (to reduce plastic cracking and impart ductility).

The panel is not showing any cracking at this time. The panel will be monitored for surface deterioration and cracking for the next twelve months, and water infiltration will be measured at such time that water escapes from the subsurface drain installed for measuring purposes.

Table 3.1 Physical Properties of Fresh Concrete

Truck Ticket No.	Concrete Volume m3	Temperature oC		Slump mm		Air Content %	
		Air	Concrete	Initial	Final	Initial	Final
131351	5	8	15	70	125	13	6.0
131359	5.5	10	15	70	215	13	5.0
131368	6	8	15	60	225	12.5	5.9
131370	6	8	15	60	230	12.5	–
131374	6	–	–	50	225	13	5.7

Table 3.2 Summary of Mechanical Properties of Concrete (Field)

Panel No. and Specimen Type	Cementitious Content kg/m3		W C+F	Compressive Strength MPa				Splitting Tensile Strength, MPa			Modulus of Elasticity, GPa			Pulse Velocity, km/s		
	Portland Cement (HSF)	Fly Ash		7d	28d	91d	365d	28d	91d	365d	28d	91d	365d	28d	91d	365d
Site cured specimens	126	252	0.37	7.4	12.3	–	–	1.21	–	–	16.7	–	–	3.86	–	–
Laboaratory cured specimens				8.6	19.6	–	–	1.87	–	–	21.8	–	–	4.07	–	–
Drilled cores				–	13.1	–	–	1.33	–	–	12.3	–	–	3.66	–	–

APPENDIX A

WORK STATEMENT

Work on the stabilization of the plant preparation waste at Victoria Junction is to be discontinued and the remaining research directed toward developing an economical cementitious sealant, using the technology developed at the Halifax International Airport. Emphasis will be placed on reducing the cost of the sealant, through the use of supplementary cementing materials, fly ash and silica fume.

The following concrete mixtures will be evaluated.

Mixture No. 1
Cement 100 kg
Fly ash 275 kg
Silica fume 25 kg

Mixture No. 2
Cement 125 kg
Fly ash 250 kg
Silica fume 10 kg

Mixture No. 3
Cement 90 kg
Fly ash 280 kg
Silica fume 10 kg

Mixture No. 4
HSF Cement 125
Fly ash 250 kg

The mixtures are to contain a maximum unit water content of 140 l/m^3 and 4 kg of 19 mm fibrillated polypropylene fibre. A superplasticizer is to be used to obtain a suitable slump for shotcreting. All mixtures are to be air entrained at 6 to 8 percent.

Testing on the mixtures are to include compressive strength at 3, 7, 28, 91 and 365 days. Flexural strengths at 28 days and 91 days. Modulus of elasticity at 28 days and 91 days. Freeze-thaw resistance by ASTM C666 method A.

CAPE BRETON DEVELOPMENT CORPORATION
P.O. BOX 2500
SYDNEY, NOVA SCOTIA, CANADA
B1P 6K9

FAX: (902) 564-2589

FACSIMILE TRANSMISSION

TO: JACQUES WHITFORD

ATT: W. S. LANGLEY **FAX NO.** 468-9009

WE ARE TRANSMITTING 1 **PAGES INCLUDING THIS PAGE. IF YOU DO NOT RECEIVE ALL PAGES, PLEASE TELEPHONE** 564 - 2894

FROM: J. C. CAMPBELL **DATE** 91-02-12

COMMENTS: DR MAHOTRA HAS PHONED ME ON CONTENTS OF MY EARLIER FAX TO YOU. TODAY.

I AGREE THAT EXAMINATION OF BLAST FURNACE SLAG BE DEFERRED TO A POSSIBLE LATER CONTRACT.

PLEASE THEREFORE PROCEED AS PER WORK STATEMENT SUBMITTED WITH YOUR FAX OF 91-02-05 TO LIMIT OF REMAINING $ VALUE OF THE CONTRACT.

A FORMAL ADDENDUM WILL BE SUBMITTED ONCE ONE IS RECEIVED FROM DSS.

REGARDS

J C Campbell

FAX TRANSMISSION

CAPE BRETON DEVELOPMENT CORPORATION
P.O. BOX 2500
SYDNEY, NOVA SCOTIA, CANADA
B1P 6K9

FAX NO.: (902) 842-2589 TELEPHONE NO.: (902) 842-2494

FROM: John C. Campbell DATE: 91-10-31

TO: W.S. Langley and Associates Ltd.
Dartmouth

FAX NO.: 468 9009 PAGE 1 OF 1

ATTENTION: Wilbert Langley

RE: Your Project # 5537

MESSAGE:

Confirming our phone conversation of yesterday. You are hereby authorized to proceed with the field work to determine the water infiltration rate of cementitious sealants. The work program to be as described in your letter to me of October 9, 1991.

Costs to be invoiced as per the basis of payment Appendix "C" of the contract dated December 31, 1988 or any revision that is acceptable to the Canmet Scientific Authority and to Supply and Services Canada. Total cost of the contract not to exceed $44,916.

Please provide an estimate of the expected expenditure to complete this phase.

Field work to begin as soon as possible and to be completed by December 31, 1991.

JC Campbell

PC&T

APPENDIX

B

Project No. 5537

FREEZE-THAW DURABILITY OF CONCRETE PRISMS
ASTM C666 - PROCEDURE A

MIXTURE NO. 1

Relative Dynamic Modulus of Elasticity, %

Specimen Number	Number of Cycles						
	0	50	100	150	200	250	300
A	100	102.8	102.8	103.0	102.3	102.4	101.9
B	100	102.6	102.9	102.1	102.4	102.4	102.4
*C	100	109.1	110.9	111.8	112.7	113.1	114.2
*D	100	108.9	110.7	111.0	111.8	113.2	114.1

Pulse Velocity, km/s

Specimen Number	Number of Cycles						
	0	50	100	150	200	250	300
A	3.84	3.99	4.02	4.03	4.07	4.04	4.09
B	3.82	3.97	4.02	4.03	4.06	4.05	4.06
*C	3.85	4.08	4.10	4.12	4.15	4.13	4.13
*D	3.82	4.10	4.12	4.05	4.12	4.10	4.12

Mass, g

Specimen Number	Number of Cycles						
	0	50	100	150	200	250	300
A	7097.9	7174.0	7159.5	7121.8	7070.3	7011.3	6993.0
B	7117.2	7179.4	7161.7	7133.9	7100.4	7058.8	7023.0
*C	7075.7	7175.4	7182.2	7183.8	7187.3	7188.0	7189.3
*D	7113.4	7208.4	7215.5	7216.6	7220.4	7221.3	7220.4

Length Change, %

Specimen Number	Number of Cycles						
	0	50	100	150	200	250	300
A	0	0.015	0.018	0.020	0.022	0.025	0.025
B	0	0.012	0.016	0.017	0.018	0.019	0.019
*C	0	0.020	0.021	0.023	0.023	0.024	0.025
*D	0	0.021	0.022	0.024	0.024	0.024	0.024

*Denotes control specimens stored at 23°C ± 2°C and 100% relative humidity.

Project No. 5537

FREEZE–THAW DURABILITY OF CONCRETE PRISMS
ASTM C666 – PROCEDURE A

MIXTURE NO. 3

Relative Dynamic Modulus of Elasticity, %

Specimen Number	Number of Cycles						
	0	50	100	150	200	250	300
A	100	100.8	101.8	101.3	101.1	101.8	102.1
B	100	101.0	–	–	–	–	–
*C	100	108.5	110.7	111.8	112.8	113.4	113.5
*D	100	109.2	111.4	111.8	112.9	113.4	114.1

Pulse Velocity, km/s

Specimen Number	Number of Cycles						
	0	50	100	150	200	250	300
A	3.72	3.89	3.93	3.91	3.96	3.96	3.94
B	3.70	3.85	–	–	–	–	–
*C	3.67	3.99	4.03	4.00	4.05	3.99	3.99
*D	3.70	4.00	4.04	4.00	4.05	4.00	3.98

Mass, g

Specimen Number	Number of Cycles						
	0	50	100	150	200	250	300
A	7029.9	7119.0	7106.8	7065.2	7034.0	6984.2	6954.4
B	6972.2	7049.3	–	–	–	–	–
*C	6936.9	7046.2	7052.6	7053.6	7057.7	7059.2	7060.9
*D	7026.5	7132.6	7138.0	7135.4	7137.1	7139.4	7142.6

Length Change, %

Specimen Number	Number of Cycles						
	0	50	100	150	200	250	300
A	0	0.011	0.013	0.016	0.017	0.018	0.018
B	0	0.016	–	–	–	–	–
*C	0	0.015	0.016	0.018	0.018	0.018	0.019
*D	0	0.020	0.020	0.022	0.023	0.023	0.023

*Denotes control specimens stored at 23°C ± 2°C and 100% relative humidity.

Project No. 5537

FREEZE–THAW DURABILITY OF CONCRETE PRISMS
ASTM C666 – PROCEDURE A

MIXTURE NO. 4

Relative Dynamic Modulus of Elasticity, %

Specimen Number	Number of Cycles						
	0	50	100	150	200	250	300
A	100	102.8	104.4	105.9	106.5	107.3	107.3
B	100	101.8	104.3	104.8	105.9	106.5	106.6
*C	100	116.9	118.6	119.6	119.9	120.7	121.3
*D	100	118.0	119.8	120.9	121.4	122.3	122.8

Pulse Velocity, km/s

Specimen Number	Number of Cycles						
	0	50	100	150	200	250	300
A	3.80	3.95	4.02	4.07	4.07	4.05	4.03
B	3.80	3.96	4.02	4.00	4.05	4.05	4.02
*C	3.76	4.14	4.20	4.17	4.21	4.18	4.21
*D	3.81	4.18	4.25	4.24	4.25	4.26	4.24

Mass, g

Specimen Number	Number of Cycles						
	0	50	100	150	200	250	300
A	7090.3	7176.8	7192.2	7201.5	7192.1	7187.1	7184.5
B	7079.1	7154.0	7169.3	7174.9	7160.1	7142.7	7130.0
*C	7099.1	7178.6	7187.3	7191.3	7198.7	7200.1	7203.0
*D	7105.5	7186.2	7196.0	7199.5	7205.3	7207.6	7213.2

Length Change, %

Specimen Number	Number of Cycles						
	0	50	100	150	200	250	300
A	0	0.014	0.019	0.023	0.024	0.024	0.024
B	0	0.014	0.019	0.021	0.022	0.023	0.023
*C	0	0.023	0.022	0.024	0.025	0.025	0.026
*D	0	0.021	0.021	0.022	0.023	0.023	0.023

*Denotes control specimens stored at 23°C ± 2°C and 100% relative humidity.

Project No. 5537

FLEXURAL STRENGTH OF FREEZE-THAW CONCRETE PRISMS AT 300 CYCLES

MIXTURE NO 1	A	3.04	MIXTURE NO 2	A	3.23
	B	2.64		B	3.45
	*C	3.55		*C	4.39
	*D	4.33		*D	5.09
MIXTURE NO 3	A	2.73	MIXTURE NO 4	A	3.29
	B	–		B	3.36
	*C	3.47		*C	4.99
	*D	3.03		*D	4.79

* Denotes control specimens stored at 23°C ± 2°C and 100% relative humidity.

Project No. 5537

FREEZE–THAW DURABILITY OF CONCRETE PRISMS
ASTM C666 – PROCEDURE A

MIXTURE NO. 2

Relative Dynamic Modulus of Elasticity, %

Specimen Number	Number of Cycles						
	0	50	100	150	200	250	300
A	100	101.2	103.0	104.0	105.0	105.5	106.0
B	100	102.3	104.2	104.9	105.0	105.0	105.5
*C	100	112.7	114.3	115.4	116.1	116.7	117.4
*D	100	112.7	114.7	115.1	116.2	116.4	117.0

Pulse Velocity, km/s

Specimen Number	Number of Cycles						
	0	50	100	150	200	250	300
A	3.93	3.99	4.04	4.09	4.10	4.06	4.10
B	3.87	3.99	4.02	4.01	4.07	4.05	4.09
*C	3.94	4.16	4.21	4.21	4.18	4.18	4.20
*D	3.96	4.17	4.19	4.20	4.23	4.21	4.23

Mass, g

Specimen Number	Number of Cycles						
	0	50	100	150	200	250	300
A	7084.5	7142.1	7160.4	7165.2	7162.4	7143.5	7131.8
B	7092.3	7162.5	7172.7	7171.0	7158.8	7137.8	7121.2
*C	7066.3	7142.2	7151.9	7157.0	7161.0	7162.8	7163.5
*D	7075.2	7148.8	7158.5	7163.5	7167.4	7169.3	7172.5

Length Change, %

Specimen Number	Number of Cycles						
	0	50	100	150	200	250	300
A	0	0.010	0.010	0.016	0.016	0.017	0.017
B	0	0.016	0.018	0.022	0.023	0.024	0.025
*C	0	0.019	0.020	0.022	0.023	0.023	0.023
*D	0	0.017	0.019	0.020	0.022	0.023	0.023

*Denotes control specimens stored at 23°C ± 2°C and 100% relative humidity.